

PROCESS FOR THE POLYMERIZATION OF ETHYLENE UNDER
SLURRY CONDITIONS

Supported chromium oxide catalysts have become an important vehicle for polymerisation of 1-olefins such as ethylene and predominantly ethylene copolymers. As originally commercialized, these polymerizations were carried out under solution conditions. However, it was early recognized that a more economical route to such polymers was to utilize a slurry system, sometimes called a particle form system, wherein the polymerization is carried out at a low enough temperature that the resulting polymer is insoluble in the diluent. It is highly desirable in slurry polymerization systems to achieve relatively high productivity. This goal is hampered to some extent by the fact that silica supported chromium oxide catalysts tend to have an induction period under slurry conditions. This is particularly disadvantageous in a slurry system utilizing a loop type reactor with a settling leg for polymer recovery.

In the polymerization of ethylene and other olefins under slurry conditions using supported chromium oxide containing catalysts, it is known to use organometallic compounds, particularly organo-aluminium compounds, as a cocatalyst or catalyst modifier, see for example, GB 2,073,761A (later published application), GB 2,048,284A, GB 1,406,339 and GB 1,241,134. In general, the suggested amounts of organometallic compound vary over extremely broad ranges e.g. 0.1 to 100%, preferably 1 to 10%, based on total catalyst weight (GB 2,073,761A); 0.5 to 50%, preferably 1 to 20%, based on total catalyst weight (GB 2,048,284A); and 0.01 to 1,000 mg, preferably 0.1 to 100 mg, per litre of diluent (GB 1,406,339). Whilst such ranges do embrace quite small quantities of organometallic compound, for practical purposes, and as illustrated in the Examples presented in those disclosures, the organometallic compounds will be used in relatively large amounts, and usually, based on the figures given in amounts substantially in excess of 5 parts per million (ppm) based on the amount of diluent e.g. about 30 ppm (Example 1, GB 2,073 761A), about 22 ppm (Example 1, GB 2,048,284A), or about 17 ppm (Example 1, GB 1,241 134).

In accordance with the present invention, however, it has been found that whilst enhancing catalyst activity, such relatively large additions of organometallic compound tend to depress the melt index and density of the product polymer. Nevertheless, it has now also been found that such disadvantages can be minimised, but at the same time maintaining substantially enhanced catalyst activity, as measured by a substantially reduced induction period, by using extremely small amounts of the organometallic compound, i.e. amounts in the range 0.2 to 1 ppm based on the weight of the diluent.

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Accordingly, there is now provide a process for the polymerization of ethylene, or of a monomer system consisting predominantly of ethylene, which comprises polymerising the ethylene, and other monomer(s) if present, in a liquid hydrocarbon diluent under slurry polymerisation conditions in the presence of a catalyst comprising chromium oxide supported on a silica-containing support material, wherein the polymerisation is conducted in the presence of from 0.2 to 1 ppm, based on the weight of diluent of (1) an organoaluminium compound of the formula R_3AL or R_2ALH , where R is C_1-C_{20} alkyl or (2) a dihydrocarbylmagnesium compound soluble in said diluent and being of the formula R'_2Mg , where R' is C_2-C_{12} hydrocarbyl.

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The polymerization process in accordance with this invention is carried out under slurry or particle form conditions, as disclosed, for instance, in Norwood, U.S. 3,248,179. Briefly, this can be accomplished, for example, by conducting the polymerization in the presence of a dry inert hydrocarbon diluent such as isobutane, n-heptane, methylcyclohexane, or benzene at a reactor temperature within the range of about 60° to about 110°C and a reactor pressure of about 1.7 to about 4.1 MPa (250 to 600 psia). The polymer can be recovered, treated with CO₂ or H₂O, for example, to deactivate residual catalyst, stabilized with an antioxidant, such as butylated hydroxytoluene (BHT), and dried by conventional methods to obtain the final product. Hydrogen can be used in the reactor as known in the art to provide some control of the molecular weight of the polymer. The polymerization can be conducted batchwise in a stirred reactor or continuously in a loop reactor with or without a settling leg or in a series of reactors.

The process of this invention is suitable for the production of normally solid ethylene homopolymer and also for the production of predominantly ethylene copolymer. Ethylene can be copolymerized with one or more higher aliphatic mono-1-olefins containing from 3 to about 10 carbon atoms such as propylene, 1-butene, 1-pentene, 1-hexene, 1-octene and/or a conjugated diolefin containing 4 to about 12 carbon atoms. In such polymers, the ethylene content generally ranges from about 97 to 99.6 weight percent which is obtained using from about 93 to 99.6 weight percent ethylene monomer, the remainder being said higher olefin comonomer. Broadly, ethylene copolymers can be made using 80 to 99.8 weight percent ethylene and 20 to 0.2 percent comonomer in the feed.

The catalyst system to which this invention applies is a supported chromium oxide system as disclosed in Hogan et al, U.S. 2,825,721. The support for the chromium oxide is a silica-containing material and can be selected from catalytic grade silica, silica-alumina, silica-boria, silica-titania, silica-zirconia, and mixtures thereof in which the silica constitutes from 80 to 100 weight percent preferably greater than 90 weight percent of the silica-containing material. Preferably, the support is a cogel, that is, a silica produced by co-precipitating titanium and silica as disclosed in Dietz, U.S. 3,887,494. For instance, this cogel formation can be carried out by adding a titanium compound to a mineral acid, introducing an alkali metal silicate into the acid containing said titanium compound to form a hydrogel, aging the hydrogel for a time of greater than one hour, washing the thus aged hydrogel to produce a substantially alkali metal free hydrogel, forming a mixture comprising the thus washed hydrogel and a normally liquid oxygen-containing water soluble organic compound, and separating said organic compound in water from said mixture to form a xerogel. The titanium is present in these cogels in an amount within the range of 0.1 to 10, preferably 0.5 to 5 weight percent titanium based on the weight of the dried cogel (xerogel).

The final solid catalyst contains chromium generally in an amount from 0.001 to 10, preferably 0.1 to 5, more preferably 0.5 to 1 weight percent chromium based on the weight of the silica-containing base. The chromium can be added initially as CrO_3 , or a lower valent chromium compound can be added and thereafter the composite activated in a conventional manner as known in the art for the particular type

of chromium compound used. Preferably, the composite is activated by contact with an oxygen-containing ambient, such as air, at temperatures ranging from 500° to 1000°C. Even if CrO_3 is utilized as a chromium source, the activation treatment is generally utilized.

In the aluminum alkyl (organoaluminum) embodiment of this invention, the aluminum alkyl is a compound of the formula R_3Al or R_2AlH where R is an alkyl radical of 1 to 20, preferably 2 to 4 carbon atoms. The preferred compound is triethylaluminum (TEA). Trimethylaluminum (TMA) is less preferred. Other suitable compounds of the formula R_3Al include tripropylaluminum, tributylaluminum and triicosylaluminum, for example. Suitable compounds of the formula R_2AlH include dimethylaluminum hydride, methylethylaluminum hydride, diethylaluminum hydride and dieicosylaluminum hydride, for example.

In the dihydrocarbyl magnesium embodiment of this invention, a compound of the formula R'_2Mg is used wherein each R' can be the same or different and is a hydrocarbyl radical, e.g. alkyl, having 2 to 12, preferably 2 to 6 carbon atoms. A particularly suitable compound is n-butylethylmagnesium (BEM). Other suitable compounds include diethylmagnesium, dipropylmagnesium, dibutylmagnesium, dipentylmagnesium, dihexylmagnesium and didodecylmagnesium. These compounds are not Grignards, i.e., they are not produced in the presence of an ether. Functionally, any R'_2Mg compound soluble in the diluent used can be utilized.

The aluminium alkyl or dihydrocarbylmagnesium compound treating agent is used in an extremely small amount i.e. within the range of 0.1 to 1 part per million preferably 0.2 to 1 part per million and more preferably 0.3 to 0.7 ppm, particularly because of the dramatic effect produced at such a low concentration. The reference herein to parts per million is based on parts by weight of the treating agent based on the weight of the diluent. At levels of about 1 part per million or less, massive reductions in the induction period are achieved with little or only modest alteration of polymer properties. At higher concentrations, polymer properties such as melt index, density and molecular weight distribution may be altered substantially.

In the following examples, the polymerization reactions were conducted in a stainless steel 3-litre stirred reactor. Ethylene was added on demand through a calibrated rotameter to maintain a constant pressure. Induction time is defined as that time required, after the desired pressure with ethylene addition has been obtained, until the first movement of the rotameter ball is noted indicating polymerization is starting. Pressurisation with ethylene took 10 minutes in each instance. Total run time is induction time, if any, plus actual polymerisation time.

When used, each metal alkyl as a dilute solution in n-hexane was added to the isobutane diluent prior to charging the monomer. It can be added before, during, or after charging the catalyst. By dilute solution is meant about 0.01 molar. For example, the TEA was 0.0108 molar, the TMA was 0.00918 molar, and BEM was 0.00413 molar.

Example I

Silica-titania cogel catalyst containing about 1 weight percent chromium as chromium oxide and about 2 weight percent titania, each based on the weight of the composition, was air activated at 870°C (1600°F) for 5 hours in dry air and used in particle form ethylene polymerization at a reactor temperature of 107°C (225°F), a reactor pressure of 3.89 MPa (565 psia) and in the presence of 635 g (1.4 L) of isobutane diluent. In the various runs about 0.03-.08 g catalyst (weighed) was charged to the reactor. A solution of trimethylaluminum (TMA) was also charged to the reactor in the amounts shown. Generally a run was conducted for a period of time estimated to yield about 4,000 g polyethylene per g catalyst. The results are given in Table I.

Table I

Run No.	Time, Minutes		TMA Conc. ppm.	Polymer			Catalyst Productivity g/g cat.	Calculated Average Catalyst Activity g/g Cat/hr
	Induction	Total		Yield g	Density g/cc	Melt Index g/10 min.		
1	4	42	None	168	0.9668	4.0	4180	5970
2	0	45	0.25	171	0.9670	3.4	4200	5600
3	0	37	0.50	175	0.9658	3.4	3900	6320
4	0	37	1.10	170	0.9662	3.4	4130	6700

This example shows the induction period to be essentially eliminated with no significant change in polymer properties such as melt index and density. Activity is improved only a small amount but this is believed to be because the control run with no adjuvant was high in activity for some unexplained reason. Example IV, Run 2 is more representative of the improvement in activity which is obtained in accordance with this invention.

18

Example II

An identical catalyst was utilized under identical polymerization conditions except that a solution of triethylaluminum (TEA) was employed as an adjuvant. The results were as follows:

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Table II

Run No.	Time, Minutes		TEA Conc. ppm.	Polymer			Catalyst Productivity g/g Cat.	Calculated Average Catalyst Activity g/g Cat/hr
				Yield g	Density g/cc	Melt Index g/10 min.		
	Induction	Total						
10								
1	5	45	None	178	0.9665	4.1	4050	5400
2	0	31	0.30	180	0.9650	3.2	4120	7970
3	0	34	0.50	179	0.9650	3.8	4200	7410
4	0	31	0.70	184	0.9652	4.4	3900	7550
15	5	31	0.96	160	0.9654	3.7	3620	7010

Catalyst activity is substantially improved with generally little change in polymer properties relative to the control. Examples IV and V hereinafter show even more dramatic improvement in activity.

Example III

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An identical catalyst was utilized under identical polymerization conditions except that a solution of n-butylethylmagnesium (BEM) was employed as an adjuvant. The results were as follows:

Table III

Run No.	Time, Minutes		BEM Conc. ppm.	Polymer			Catalyst Productivity g/g Cat.	Calculated Average Catalyst Activity g/g Cat/hr
				Yield g	Density g/cc	Melt Index g/10 min.		
	Induction	Total						
25								
1	10	55	none	216	-	3.9	4240	4630
30	2	35	1.00	240	-	3.4	4290	7350

Catalyst activity is substantially improved while little change is noted in polymer melt index relative to the control. Polymer density was not determined.

Example IV

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Davison 969 MS catalyst containing 1 weight percent chromium as chromium oxide, the remainder being silica, was air activated at 816°C (1500°F) for 6 hours and used to produce polyethylene under identical polymerization conditions in the absence, and in separate runs, in the

presence of one of 0.50 ppm of TMA, 0.50 ppm TEA and 0.50 ppm (triethylborane (TEB) as reactor adjuvant. The results were as follows:

Table IV

5	Polymer							Calculated	
	Time, Minutes		Metal	Yield	Density	Melt	Catalyst	Average	
10	Run No.	Induction	Total	Alkyl	g	g/cc	Index g/10 min.	Catalyst Productivity g/g Cat.	Catalyst Activity g/g Cat/hr
	1	35	78	none	176	0.9665	0.48	4000	3080
	2	1	42	TMA	225	0.9614	0.32	4120	5890
	3	0	39	TEA	246	0.9610	0.30	4430	6820
	4	0	66	TEB	221	0.9616	0.40	4000	3640

In this series with a silica supported chromium oxide catalyst, TEB provided little improvement in catalyst activity while TMA and TEA each provided great improvement. Each metal alkyl depressed polymer density slightly more than in the other runs for some unexplained reason but the density was still not depressed below typical homopolymer density.

Example V

Catalyst identical to that of Example IV except that it was activated at 1400°F was employed in polymerizing ethylene containing 6 weight percent 1-hexene based on the total weight of monomers under polymerization conditions generally similar to those before. One half of the 1-hexene was added prior to starting the run, the remainder was added along with the ethylene required to maintain the desired pressure. Thus, an average 6 weight percent 1-hexene content based on total monomers was maintained throughout the run. When used, TEA or butylethylmagnesium (BEM) adjuvant was added to the reactor. The results were as follows:

Table V

Run No.	Time, Minutes		Run Temp °C	Metal Alkyl ppm.	Polymer		Melt Index g/10 min.	Catalyst Prod. g/g Cat.	Calculated Average Catalyst Activity g/g Cat/hr
					Yield g	Density g/cc			
1	38	98	102	none	202	0.9470	0.14	4300	2630
2	0	35	102	0.73 TEA	134	0.9478	0.17	3150	5400
3	0	40	102	1.48 TEA	207	0.9460	0.17	4480	6720
4	27	82	104	none	207	0.9482	0.42	4040	2960
5	0	40	104	0.82 TEA	143	0.9476	0.33	3530	5300

25

6	18	68	104	none	203	0.9436	0.63	3940	3480
7	0	30	100	1.00 BEM	187	0.9552	1.8	4140	8280

As can be seen, both the TEA and BEM gave massive improvements in activity.

Example VI

5 A silica-titania-chromia tergel catalyst was prepared as
generally disclosed for the cogel catalyst except that a water-soluble
chromium compound was admixed with the titanium compound and acid. The
final catalyst, dry basis, contained 1 weight percent chromium as chrom-
ium oxide and 2 weight percent titanium as titanium oxide. The catalyst
10 was activated for 5 hours at 870°C in dry air. About one-half of the
weight of comonomer was charged to the reactor prior to starting the run.
The remainder was added along with the ethylene required to maintain the
desired pressure during the first 20 minutes of the actual polymerization
time. When used, BEM adjuvant was added to the reactor in the concentra-
15 tion shown. The results were as follows. Runs 1 and 2 were run at 550
psig (3.8 MPa) while runs 3-6 were run at 350 psig (2.4 MPa).

Table VI

Run No.	Time, Minutes		Run Temp °C	BEM Conc ppm.	Comonomer		Polymer		Melt Index g/10 Min	Catalyst Productivity g/g Cat	Calculated Average Catalyst Activity g/g Cat/hr
	Induction	Total			Name	Wt. % In Feed	Yield g	Density g/cc			
1	30	70	100	0	1-hexene	5.2	405	0.9468	3.0	7440	6380
2	0	30	100	1.0	1-hexene	3.9	230	0.9466	3.0	4330	8660
3	16	91	90	0	1-octene	5.4	176	0.9364	2.4	3830	2530
4	5	63	90	2.0	1-octene	5.1	185	0.9348	0.89	4060	3870
5	50	130	85	0	1-octene	3.8	189	0.9454	0.32	4375	2020
6	0	60	85	2.0	1-octene	8.7	187	0.9412	0.14	3900	3900

In every instance, 1 or 2 ppm BEM addition improved catalyst activity. In runs 1, 2, it can be seen that at 1 ppm BEM and with 1-hexene as comonomer, both polymers made were substantially equivalent in melt index and density. The advantage of 1 ppm BEM lies in the greater catalyst activity coupled with little or no change in polymer properties.

In runs 3, 4 and 5, 6, the results indicate that 2 ppm BEM, while improving catalyst activity, depressed both polymer melt index and polymer density below that of the control polymers. This coupled with previous data shows that as little as 1 ppm or even 0.5 ppm and less have a dramatic effect on reducing the induction period and increasing activity with little effect on polymer properties. At the higher (but still very low) concentrations, the same beneficial effects in induction period and activity are achieved but polymer properties begin to be affected.

Control Example VII

A catalyst identical to that of Example I was utilized under identical polymerization conditions except that a solution of triethylborane (TEB) was employed as an adjuvant. The results were as follows:

Table VII

Run No.	Time, Minutes		TEB Conc ppm.	Polymer			Catalyst Productivity g/g Cat	Calculated Average Catalyst Activity g/g Cat/hr
	Induction	Total		Yield g	Density g/cc	Melt Index g/10 min.		
1	8	53	0	171	0.9664	4.3	4090	4630
2	0	48	0.29	165	0.9658	4.2	4090	5110
3	0	50	0.49	167	0.9658	3.5	3850	4620
4	0	50	1.00	175	0.9654	3.3	4300	5160

Addition of TEB generally results in depressing both polymer melt index and density slightly with little improvement in activity. This shows that not just any metal alkyl will function at low concentrations to both decrease the induction period and increase activity significantly. This is consistent with Control Run 4 of Example IV.

Tests with diethylzinc show that alkylzinc compounds are also ineffective to improve activity in the concentration range used with the other metal alkyls.

CLAIMS

1. A process for the polymerisation of ethylene, or of a monomer system consisting predominantly of ethylene, which comprises polymerising the ethylene, and other monomer(s) if present, in a liquid hydrocarbon diluent under slurry polymerisation conditions in the presence of a catalyst comprising chromium oxide supported on a silica-containing support material, wherein the polymerisation is conducted in the presence of from 0.2 to 1 ppm, based on the weight of the diluent of (1) an organo-aluminium compound of the formula R_3AL or R_2ALH , where R is C_1-C_{20} alkyl or (2) a dihydrocarbylmagnesium compound soluble in said diluent and being of the formula R'_2Mg , where R' is C_2-C_{12} hydrocarbyl.
2. A process according to claim 1 wherein the polymerisation is carried out in the presence of a trialkylaluminium compound.
3. A process according to claim 2 wherein the trialkylaluminium compound is triethylaluminium.
4. A process according to claim 1 wherein the polymerisation is carried out in the presence of a dihydrocarbylmagnesium compound.
5. A process according to claim 4 wherein the dihydrocarbylmagnesium compound is n-butylethylmagnesium.
6. A process according to any one of the preceding claims, wherein said organoaluminium compound or dihydrocarbylmagnesium compound is present in an amount of from 0.3 to 0.7 parts per million based on the weight of said diluent.
7. A process according to any one of the preceding claims wherein the monomer consists entirely of ethylene; or comprises 93 to 99.6 weight percent ethylene, the remainder being at least



24

one C₃ to C₁₀ olefin.

8. A process according to any one of the preceding claims wherein the diluent is isobutane.

9. A process according to any one of the preceding claims wherein said catalyst support is a silica-titania cogel.

10. A process according to claim 1, which comprises polymerising ethylene, or a monomer system consisting predominantly of ethylene, under slurry conditions in isobutane at a temperature of from 60-110°C in the presence of a catalyst comprising about 1% by weight of chromium oxide supported on a silica-titania cogel, wherein the polymerisation is effected in the presence of from 0.2 to 1 ppm, based on the weight of the diluent, of triethylaluminum or n-butylethylmagnesium.

